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Innovative and Proven Remediation Technologies

This page contains descriptions of several new, emerging, and proven technologies for the remediation of contaminated soil and water. Many of the technologies have been evaluated by PRIMA for the chemicals of concern (COCs) listed, though PRIMA makes no claim as to the general efficacy of any technology. Note that the list of COCs commonly removed by a given technology may not be all-inclusive and COCs generally removed may not be removed in all situations. An understanding of the technology, the COCs to be removed, and the site conditions are all necessary to the successful application of a technology.

On the following table, hover over each technology name for a pop-up description.
You can also click to the right of the name to go to a detailed description.

Below the table, you will find a detailed list of the technologies.

Disclaimer: Many of these technologies (or variations thereof) are protected by patents and require a license to use. PRIMA assumes no legal responsibility for the improper use of these technologies under any patents.

Technology / Reagent	Chemical of Concern														
	Organic Compounds										Inorganic Compounds				
	BTEX	MTBE	Petroleum Hydrocarbons (TPH)	PAHs	chlorinated ethanes	chlorinated ethenes (PCE, TCE, DCE, VC)	chlorinated methanes (CT, CF, DCM)	Pesticides (e.g. Dieldrin, DBCP)	Pentachlorophenol	1,4-dioxane	Arsenic	Cr(VI)	Metals	Nitrate	Perchlorate
Biological Treatments - aerobic															
Hydrogen Peroxide	✓	✓	✓	--	S	S	--	--	--	--	--	--	--	--	--
ORC™	✓	--	✓	--	--	--	--	--	--	--	--	--	--	--	--
PermeOx®	✓	--	✓	--	--	--	--	--	--	--	--	--	--	--	--
Oxygen / Air Sparging	✓	--	✓	--	--	--	--	--	--	--	--	--	--	--	--
Biological Treatments - anaerobic															
Electron Donor/Carbon source (general)	--	--	--	--	✓	✓	✓	S	--	--	--	✓	--	✓	✓
EHC® *	--	--	--	--	✓	✓	✓	S	--	--	--	✓	--	✓	✓
EOS®	--	--	--	--	✓	✓	✓	S	--	--	--	✓	--	✓	✓
HRC®	--	--	--	--	S	✓	✓	S	--	--	--	✓	--	✓	✓
Newman Zone®	--	--	--	--	✓	✓	✓	S	--	--	--	✓	--	✓	✓
Chemical Oxidants															
Activated persulfate	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	--	--	--	--	--
Catalyzed Hydrogen Peroxide (Fenton's Reagent)	✓	✓	✓	✓	✓	✓	✓	S	✓	✓	--	--	--	--	--
Klozur ® CR	✓	✓	✓	✓	✓	✓	✓	✓	--	✓	--	--	--	--	--
Ozone	✓	✓	✓	✓	S	✓	S	S	✓	✓	--	--	--	--	--
Ozone+peroxide (Perozone)	✓	✓	✓	✓	S	✓	S	S	✓	✓	--	--	--	--	--
Permanganate	--	--	--	--	--	✓	--	S	✓	--	--	--	--	--	--
Chemical Reductants															
Ascorbic acid (Vitamin C)	--	--	--	--	--	--	--	--	--	--	--	✓	--	--	--
Calcium polysulfide (CaSx)	--	--	--	--	--	--	--	--	--	--	✓	✓	✓	--	--
Sulfur Modified Iron (SMI®)	--	--	--	--	S	✓	S	S	--	--	✓	✓	S, A	✓	--
Sodium dithionite	--	--	--	--	--	--	--	--	--	--	--	✓	--	--	--
Zero-valent iron (ZVI)	--	--	--	--	S	✓	S	S	--	--	✓	✓	S, A	✓	--
Other															
VTX^	n.a.^														
Stabilizing Agents															
Cement	--	--	--	--	--	--	--	--	--	--	✓	--	S	--	--
Lime (CaO2)	--	--	--	--	--	--	--	--	--	--	--	--	S	--	--
Phosphate	--	--	--	--	--	--	--	--	--	--	--	--	S	--	--

Notes:

Table is not all-inclusive. COCs may also be removed by treatments not listed here. Treatments may not be effective under all conditions.

"✓": normally effective toward this COC

"--": not treated or effectiveness unknown

"S" : some compounds in this class may be treated

"A" : metals may be removed via adsorption and/or precipitation

* chemical reduction may also occur

^ catalyst for activated persulfate or catalyzed hydrogen peroxide

BIOLOGICAL TREATMENTS – AEROBIC

Hydrogen Peroxide

In situ application of H_2O_2 alone can be used to enhance aerobic biodegradation since H_2O_2 decomposes to oxygen gas (1L of 1% H_2O_2 produces approximately 3L of oxygen gas). Significant chemical oxidation is unlikely because H_2O_2 is a weak oxidant compared to reagent CHP. However, in some cases, metals naturally present in water or soil could serve as catalysts, enabling CHP-type chemistry to occur.

ORC®

Oxygen Release Compound (ORC®) and ORC® Advanced are proprietary reagents that, when hydrated, slowly decompose to generate oxygen. ORC® may be obtained from Regenesis.

PermeOx®

PermeOx® and PermeOx® Plus are proprietary reagents that, when hydrated, slowly decompose to generate oxygen. They may be purchased from the manufacturer, FMC, or from an FMC distributor such as Chem Rem.

Oxygen / Air Sparging

Many COCs readily undergo aerobic biodegradation, but are oxygen-limited in the sub-surface. Oxygen may be added by sparging with air or with nearly pure oxygen, which may be generated on site via an oxygen concentrator.

BIOLOGICAL TREATMENTS - ANAEROBIC

Electron Donors (general)

Addition of an electron donor (carbon source) can stimulate biodegradation in many ways. Most commonly, an electron donor is added to provide food for microorganisms that will consume oxygen and stimulate anaerobic biodegradation. Electron donors tested by PRIMA include cheese whey (a by-product of cheese manufacturing), ethanol, lactic acid/lactate, molasses, emulsified vegetable oil (EOS®, Newman Zone®), and EHC®.

EHC®

EHC®, developed by Adventus Group, is a family of products that combines a carbon source and zero-valent iron (ZVI) in such as to produce very strong reducing conditions. This enables remediation to occur via anaerobic biodegradation and or chemical reduction.

EOS®

EOS® is a family of emulsified soybean oil developed by EOS Remediation. EOS® provides a long-term carbon source for microorganisms, thereby stimulating anaerobic biodegradation.

HRC®

HRC® is a family of products designed to slowly release the electron donor lactic acid, which stimulates anaerobic biodegradation. HRC® may be obtained from Regenesis.

Newman Zone®

Newman Zone® is a proprietary mixture of fast and slow release electron donors that promotes anaerobic biodegradation. Newman Zone® can be obtained from RNAS.

CHEMICAL OXIDANTS

Activated Persulfate

Activated persulfate is an established technology for the oxidation of a wide range of organic compounds, though the efficacy of treatment may depend upon the activator used. Persulfate alone is a relatively strong oxidant, but activation generates the sulfate radical, which is an even stronger oxidant. Common activators include heat, divalent metals, chelated metals (e.g. iron EDTA), hydrogen peroxide, calcium peroxide, and high pH (pH > 10.5). Persulfate decomposes to generate sulfuric acid. The change in sulfate concentration and the effect on pH depend upon the amount of persulfate used and the buffering ability of site soil and groundwater, among other factors. Other potential secondary effects include oxidation of soil chromium to Cr(VI) and mobilization of metals due to changes in pH. The magnitude, duration, and significance of any such affects are site specific.

Catalyzed Hydrogen Peroxide (aka Fenton's Reagent)

Catalyzed hydrogen peroxide (CHP) is a mixture of hydrogen peroxide (H_2O_2) and a catalyst that generates radicals, which are stronger oxidants than H_2O_2 alone. If the catalyst is acidified ferrous iron, the mixture is known as Fenton’s Reagent. If the catalyst is used at near-neutral pH, the mixture is sometimes referred to as modified Fenton’s Reagent. Catalysts that may be used at near-neutral pH are often proprietary and include chelated iron (application of which may be covered by patents held by ISOTEC, VTX, or nano-scale ZVI. CHP decomposes to oxygen and water (1L of 1% H_2O_2 produces approximately 3L of oxygen gas). The reaction is exothermic, though the temperature increase may be negligible or significant depending upon the concentration of H_2O_2, the rate at which it decomposes, and other factors. Contaminants can be completely oxidized to carbon dioxide and water.

Klozur® CR

Klozur® CR is a form of activated persulfate. It is a pre-blended mixture of sodium persulfate and PermeOx Plus, which enables alkaline activation of persulfate as well as formation of dissolved oxygen. Klozur® CR may be purchased from the manufacturer, FMC, or from an FMC distributor such as ChemRem.

Ozone

Ozone gas is a strong oxidant that can react with a wide range of organic compounds, potentially converting them to carbon dioxide and water; ozone itself decomposes to oxygen gas. Possible secondary effects of in situ treatment using ozone include formation of Cr(VI) from soil chromium and formation of bromate from naturally occurring bromide. The magnitude, duration and significance of secondary effects are site specific.

Ozone + Hydrogen Peroxide

Ozone + hydrogen peroxide is an advanced oxidation process (AOP) that may be more effective toward some COCs than ozone alone (especially when used ex situ) because it can generate the hydroxyl radical, an even stronger oxidant than ozone or peroxide alone. The presence of hydrogen peroxide may also reduce the likelihood of Cr(VI) and bromate formation.

Permanganate

Permanganate is a moderately strong oxidizing agent that is available as solid potassium permanganate (KMnO4) or liquid sodium permanganate (NaMnO4). It is most commonly used to oxidize chlorinated ethenes (PCE, TCE, DCE and VC), but has also been shown to react with pentachlorophenol and the pesticides Aldrin and Dieldrin. Permanganate reacts with some natural organic matter and other oxidizable species in soil, and in many cases, the soil oxidant demand (SOD) rather than the COC mass, determines the amount of permanganate required at a site. The most common side effect of in situ treatment using permanganate is oxidation of soil chromium to Cr(VI). The amount of Cr(VI) formed and its ability to attenuate are site-specific.

CHEMICAL REDUCTANTS

Ascorbic Acid (Vitamin C)

The scientific literature describes the use of ascorbic acid for the treatment of acute chromate poisoning. Detoxification occurs via reduction of Cr(VI) to Cr(III). Laboratory testing conducted by PRIMA has shown that ascorbic acid can reduce Cr(VI) in groundwater.

Calcium Polysulfide (CaSx)

CaSx, sold under the brand names Calmet® and Cascade®, is a dark orange-red liquid with pH ~ 11 that is used to treat Cr(VI) and heavy metals in soil and water. Cr(VI) is removed via reduction of Cr(VI) to Cr(III), while metals are stabilized via formation of water-insoluble sulfides or oxides.

Sulfur-Modified Iron (SMI-III™)

SMI-III™ is a patented, granular media that has been developed for removal of arsenic(III), arsenic(V), nitrate, Cr(VI), metals, and chlorinated solvents from water. It is NSF Standard 61 Certified for use with drinking water and may be used alone or in conjunction with traditional adsorption media. Spent SMI is recyclable. The mechanism of contaminant removal depends upon the contaminant. For arsenic and metals, removal occurs via adsorption. For Cr(VI), removal may occur by adsorption of Cr(VI) or by reduction of Cr(VI) to Cr(III), followed by adsorption or precipitation of Cr(III). Removal of nitrate occurs via chemical transformation (reduction) to ammonia and other, unidentified products. Chlorinated solvents are presumably removed via reductive dechlorination. SMI can be obtained from Loprest Water Treatment Company.

Sodium Dithionite

Sodium dithionite is a reducing agent that can be used to indirectly convert Cr(VI) to Cr(III). Dithionite is injected into the sub-surface, where it reduces naturally occurring ferric iron in soil to ferrous iron. As Cr(VI)-laden groundwater moves through the ferrous iron zone, Cr(VI) is converted to Cr(III), which will precipitate at near-neutral pH.

Zero-valent Iron (ZVI)

Zero-valent iron (ZVI) is an established technology for the removal of many chlorinated compounds from aqueous solution. Removal is destructive, often resulting in complete dechlorination given sufficient contact time. ZVI can also destroy nitrate, convert Cr(VI) to Cr(III) and sorb arsenic and metals such as uranium. ZVI is most frequently used for in situ, passive remediation of groundwater. Common emplacement techniques include creating a permeable reactive barrier (PRB) in which a trench is dug perpendicular to the direction of groundwater flow and back-filled with granular ZVI, and hydraulic or pneumatic fracturing in which the fractures are filled with micro-scale ZVI. Nano-scale ZVI may be emplaced via injection of a slurry.

OTHER

VTX

VTX is a proprietary, non-toxic liquid catalyst developed by Advanced Oxidation Technology, Inc. for use with oxidants such as hydrogen peroxide, ozone and persulfate at near-neutral pH. Field and bench tests have shown that VTX, combined with a suitable oxidant, can treat many compounds including TCE, PCE, MTBE, and BTEX.

STABILIZING AGENTS

Cement

Addition of cement to soil will increase pH, thereby forming metal hydroxides, many of which are virtually insoluble in water. Depending upon the amount of cement added, the soil may also be solidified.

Lime (CaO_2)

Addition of lime to soil or water will raise the pH, thereby forming metal hydroxides, many of which are insoluble in water. Unlike cement, lime will not solidify soil.

Phosphate

Addition of phosphate to lead-impacted soil can be a very effective treatment because phosphate reacts with lead to form lead phosphate, which is extremely insoluble in water and is not readily bioavailable.